Ontario

Ministry of Transportation
Materials Engineering and Research Office Report

A New Test Method To Investigate Pull-Out Resistance of Hot-Poured Rubberized Asphalt Sealants

MERO-021

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Abstract

The Ministry of Transportation of Ontario (MTO) has found that routing and sealing using hot-poured rubberized asphalt sealants has generally been an effective pavement maintenance strategy for asphaltic concrete pavements. However, in recent years, adhesive failures of rout and seal have become more prevalent in pavements which are constructed with certain aggregate types.

Since, the so-called "bond test" (ASTM D 5329), which was originally developed for concrete joint sealants, has sometimes proved to be somewhat unreliable in predicting pull-out resistance in asphaltic concrete pavements, a project was undertaken by the Bituminous Section to develop a test procedure in which hot-poured rubberized asphalt sealant is pulled out of a fabricated groove in a gyratory-compacted specimen of asphaltic concrete.

This new test was successfully used to rank aggregates on the basis of their relative "pull-out resistance" with the mafic (i.e. dark minerals rich) gneissic and volcanic aggregates appearing to be exhibit significantly more resistant than the felsic (i.e. feldspar-rich) diorite, migmatite and meta-arkose aggregates.

In addition, the results based on this test procedure, show that the 20 mm wide and 20 mm deep rout configuration consistently had higher pull-out resistance than the 40 mm wide by 10 mm deep configuration that MTO is currently using. However, past experience has shown that Contractors have much more difficulty in centreing a crack within a 20 mm wide rout than with the 40 mm wide configuration.

Key Words	Hot-poured rubberized asphalt sealants, routing and sealing, sealants.
Distribution	Unrestricted technical audience.

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Executive Summary

The Ministry of Transportation of Ontario (MTO) has found that routing and sealing using hot-poured rubberized asphalt sealants has generally been an effective pavement maintenance strategy for asphaltic concrete pavements. However, in recent years, "pull-out" failures of rout and seal have appeared to become more prevalent in pavements which are constructed with certain aggregate types.

One test that is often used to predict the performance of sealants is the so-called "bond test" (ASTM D5329-04) which was originally developed for concrete joint sealants. However, since this procedure suffers from several deficiencies including the use of Portland cement concrete blocks comprised of unspecified aggregates (Masson, 2000), it has sometimes proved to be somewhat unreliable in predicting sealant performance in asphaltic concrete pavements.

A project was undertaken by the Bituminous Section to develop a test procedure in which a hot-poured rubberized asphalt sealant is stripped out of a fabricated groove in a specimen of asphaltic concrete compacted in a Superpave Gyratory Compactor (SGC).

This new test was successfully used to rank aggregates on the basis of their relative "pull-out resistance" for a given type of sealant tested. The results show that the mafic (i.e. dark mineral rich) gneissic and volcanic aggregates exhibited significantly more resistance to "pull-out" than the felsic (i.e. feldspar-rich) diorite, migmatite and meta-arkose aggregates.

In addition, the results based on this test procedure show that the 20 mm wide and 20 mm deep rout configuration consistently showed higher pull-out resistance than the 40 mm wide by 10 mm deep configuration that MTO is currently using. However, past experience has shown that Contractors appear to have much more difficulty in centering a crack within a 20 mm wide rout than in the much wider configuration that MTO is currently using. Based on the findings in this report, it is now recommended that other configurations like a 20 mm wide by 20 mm deep or 30 mm wide by 15 mm deep rout cross section be adopted and that the centerline tolerances for crack versus rout be strictly enforced.

Introduction / Background

The Ontario Ministry of Transportation (MTO) has been using routing and sealing as an effective pavement maintenance strategy in asphaltic concrete pavements for many decades. However, during the mid-1990's, sealant failures began to become much more common.

Although investigations showed that most of the failures were related to workmanship issues surrounding the application of the sealants, it appeared that some of the failures may have been related to pavements constructed with certain aggregate types. Adhesive failure (i.e. stripping) of sealants became an important issue which needed to be investigated.

One test that has been used to predict the performance of sealants is the so-called "bond test", described by ASTM (D5329-04) which was originally developed for concrete joint sealants. In that test, a sealant is poured between two small concrete blocks and then cooled to a specified temperature. The blocks are then placed in an extension machine and pulled apart at a uniform rate until the sample is extended a specified amount. However, in addition to using Portland cement concrete blocks, this procedure suffers from several other deficiencies (Masson, 2000) and, as a result, has sometimes proved to be somewhat unreliable in predicting sealant performance in asphaltic concrete pavements.

A project was undertaken by the Bituminous Section to develop a test procedure which could be used to more accurately predict possible failures in routed cracks before sealants are actually approved for use.

Literature Review

A literature review was conducted to investigate testing procedures that appeared to be more suitable for predicting rout and seal performance in asphaltic concrete pavements.

One recent investigation that was carried out (Carrick *et. al.*, 2002) used core and block samples of asphalt with routed and sealed grooves. In that investigation, routing was carried out on sections of pavement and then cores were taken through the routed sections or sawed around them as block samples. Once the samples were removed, a thin metal strip was placed along and slightly suspended above the bottom of the grooves. The hot sealant was poured around the strip and then the cores and block samples were conditioned in water. The conditioned samples were then placed in an Instron machine and subjected to tensile load (i.e. pulled straight up) at a constant loading rate until the sealant "plug" was pulled out, recording the load at failure. Although the methodology used in this particular test was certainly more appropriate than the bond test (ASTM D 5329-04) which uses Portland cement concrete blocks, it did not adequately simulate the "peeling" action of sealants which appears to occur during failures (especially longitudinal failures) in the field. In addition, the procedure involved the complications of using a contractor's router and removing samples of pavement from an actual roadway.

Another test conducted during the same investigation, (Carrick *et. al.*, 2002) involved the use of similarly-prepared block samples which were then placed in an Asphalt Pavement Analyzer (APA). In this test, a small rubber wheel applying a constant contact pressure moved back-and-forth over the sealant strip several thousand times. Periodically, the test was stopped and the bond visually inspected. Although this test was certainly better at simulating traffic action than the previous method, it did not produce a quantitative measure of stripping resistance since the evaluations were done visually. In addition, as in the previous test, it still involved the complications of using a router and removing samples of pavement from an actual roadway.

The MTO decided to develop a procedure that would not be dependent on taking field samples but would still be able to adequately simulate the peeling action of sealants from routed grooves in conditioned asphalt pavements. It was decided that a quantitative measure of "pull-out resistance" was required and that the samples should be completely fabricated and tested within the laboratory using existing equipment.

Laboratory Investigations

Laboratory Procedure

Since Marshall briquettes were much too small, it was decided that the specimens would be fabricated using the Superpave Gyratory Compactor (SGC). Standard grooves were made in the Gyratory briquettes by placing stainless steel "plugs" within the mold. One "plug" was placed on the bottom of the mold and the other on top of the loose sample of hot-mix asphalt. One of the plugs was used to simulate the 20 mm wide by 20 mm deep rout configuration that MTO once used and the other was used to simulate the 40 mm wide by 10 mm deep groove that is currently being used (Figure 1). Both plugs had slightly smaller dimensions than the routs that they were trying to simulate. The wider ends of the "plugs" were used to accommodate clamping plates and other hardware which would eventually be attached to a testing frame. The samples were then compacted in a gyratory compactor to the number of gyrations required to provide each briquette with about 7% air voids.

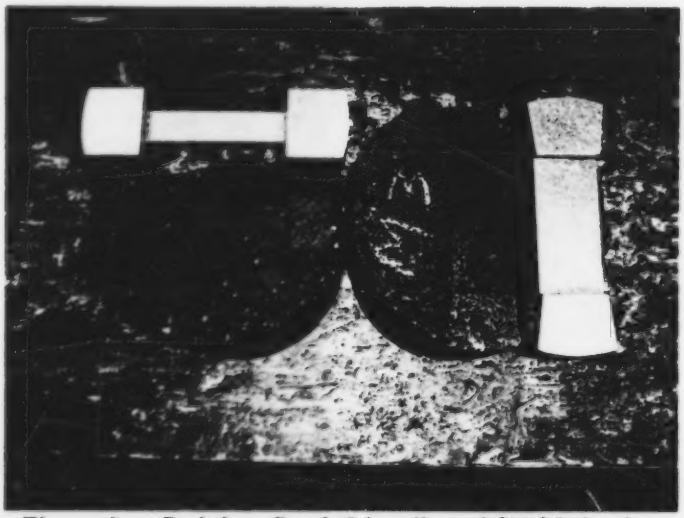

Figure 1 – Stainless Steel "Plugs" used for fabricating grooves

The steel plugs were then removed and the briquette was cut in half to provide two separate test specimens. The fabricated groove in each test specimen was then slightly enlarged to its final dimensions using a pneumatic hammer equipped with various chisels (Figure 2).

Since routing of the grooves would have been extremely difficult to do and impractical in a laboratory setting, it was felt that the chiselling action with a pneumatic hammer would be a good approximation of the aggressive impact that aggregates experience when being routed in the field.

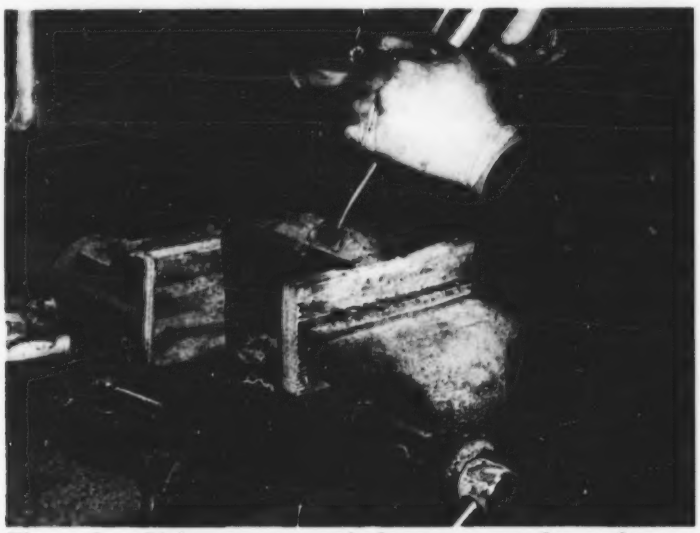

Figure 2 – Using a pneumatic hammer to enlarge the groove and expose the aggregates

The grooves were lightly cleaned and then hot-poured rubberized asphalt sealant was poured into them in two layers with a reinforcing wire mesh (slightly smaller than the fabricated groove) placed between the layers.

The wire mesh was added to the sealant to inhibit the stretching which was found to be a problem during initial development of the test procedure. At each end of the sealant strip, a bolt passed through two steel clamping plates placed above and below the sealant (Figure 3).

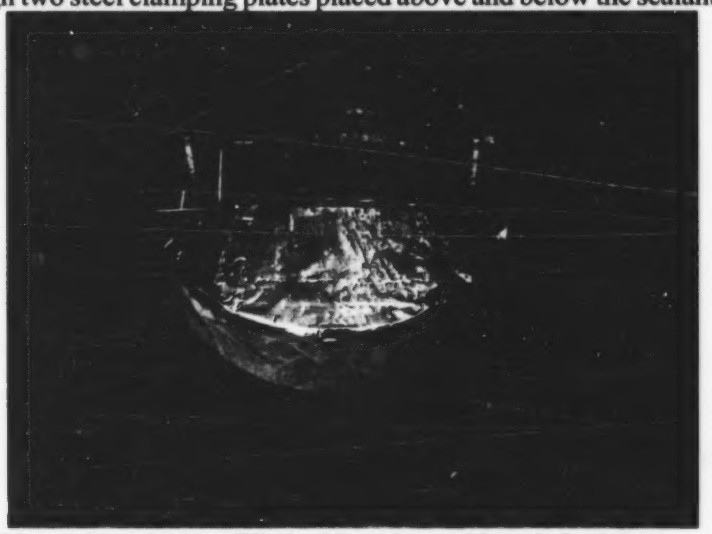

Figure 3 – Groove filled with sealant with end clamping plates

About one-third of the specimens were left unconditioned while the remainder were conditioned using two different methods (see next section). Each specimen was then placed into an MTS testing frame with the ends of the sealant strip being connected to the load application equipment using the protruding bolts. Both ends of the sealant strip were simultaneously pulled up at a constant rate (Figure 4) and the average force required to pull the sealant strip away from the constant cross section within the prepared groove was measured.

The average sealant stripping stress in kPa per linear metre was then calculated using the average force divided by the average cross-sectional area (i.e. rout width plus twice the depth multiplied by the unit length) between the "Start Point" and the "End Point" within the constant cross section. The "Start Point" occurred when the bottom inside-edge of the bottom clamping plates at both ends of the test strip were elevated above the top surface of the asphalt specimen (i.e. when the a's and b's were coincident with one another as shown in Figure 4). The "End Point" occurred whenever the technician first observed separation at any location along the sides or bottom of the constant cross section.

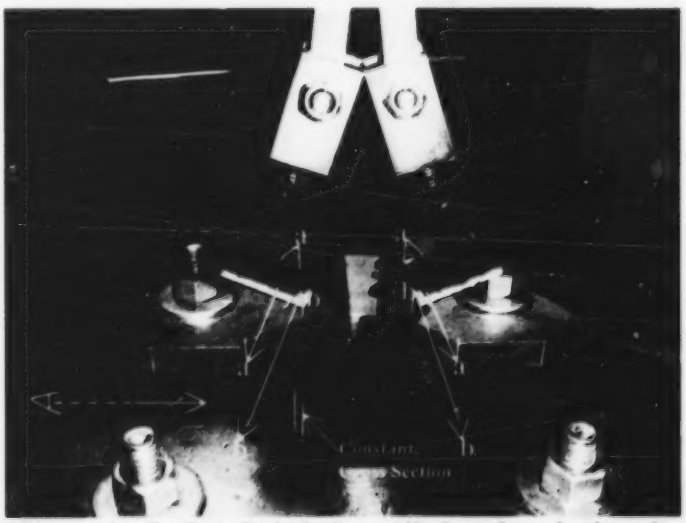

Figure 4 – Sealant Strip being pulled up from both ends

About one-third of the specimens were left unconditioned while the remainder were conditioned using two different methods (see next section). Each specimen was then placed into an MTS testing frame with the ends of the sealant strip being connected to the load application equipment using the protruding bolts. Both ends of the sealant strip were simultaneously pulled up at a constant rate (Figure 4) and the average force required to pull the sealant strip away from the constant cross section within the prepared groove was measured.

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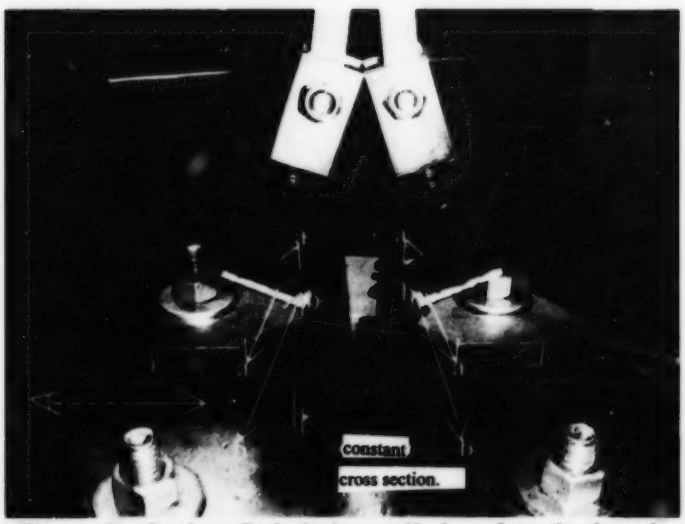


Figure 4 – Sealant Strip being pulled up from both ends

Laboratory Testing

Although a standard mix design could have been used, it was decided that actual mix designs (i.e. that are currently in service) would be used. The coarse aggregates in the mix designs were derived from the following 8 rock types or lithologies (their locations and mix types):

- Amphibolite Gneiss (Parry Sound - HL-1)
- Biotite Gneiss (Waubaushene - DFC)
- Diorite (Crooked Bay – HL3 Mod.)
- Meta-Arkose (Washago - DFC)
- Meta-Gabbro (Huntsville - DFC)
- Migmatite (North Bay- HL3 Mod.)
- Quartzite (Little Current – HL3 Mod.)
- Traprock (Marmora - DFC)

The mixes were made using the coarse and fine aggregate components from the actual Marshall mix designs but with the same Performance-Graded (PG 58-34) binder. Anti-stripping additives were used, if they were specified in the original design.

Two different hot-poured rubberized asphalt sealants were also used in the testing to investigate the differences between sealants.

Although, a number of different types of conditioning were initially investigated to artificially age the specimens, it was eventually decided that the following three methods would be used, to compare the various aggregate types:

1) Non-conditioned
2) Vacuum saturation
3) Vacuum saturation with one freeze/thaw cycle (ending with a water bath at 25°C)

The conditioning was carried out after the sealant had been poured into the grooves and generally followed the requirements given in Section 10.3.1 of AASHTO T-283-03.

At least 2 and in some cases, up to 4 or 5 samples were tested for each different combinations of mix design, fabricated rout cross section, sealant and conditioning method. About 300 tests were conducted in total with about 100 done during the initial development of the procedure itself and almost 200 during the testing phase of this investigation.

Summary of Results/ Findings

Summary of Results

Most of the laboratory results have been presented in a series of bar graphs (based on averages of two to four tests), for comparing how the pull-out resistance (in kPa per linear metre) of various aggregates (i.e. rock types) changes when they are subjected to different methods of conditioning, sealants and rout configurations.

Figure 5 shows how the conditioning method affects the results when Sealant "A" is used with the 40 X 10 rout configuration and Figure 6 shows the results for the 20 X 20. Similar comparisons are also shown in Figures 7 and 8 for Sealant "B".

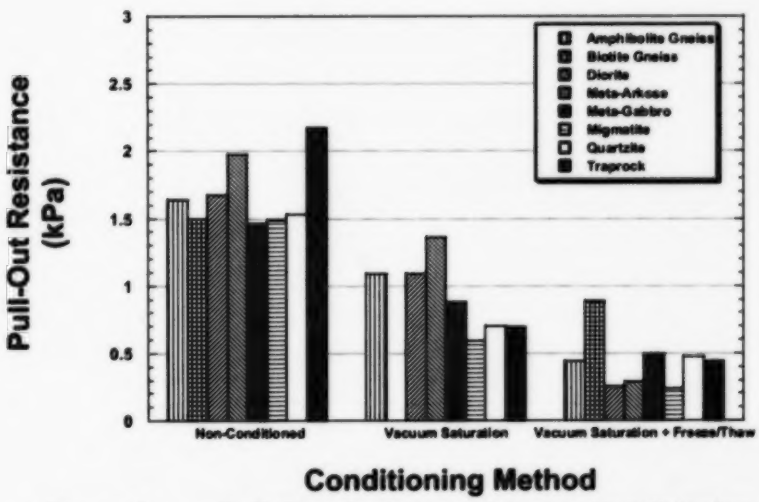


Figure 5 - Pull-Out Resistance Versus Conditioning Method (Sealant "A" – 40 by 10 Rout Cross Section)

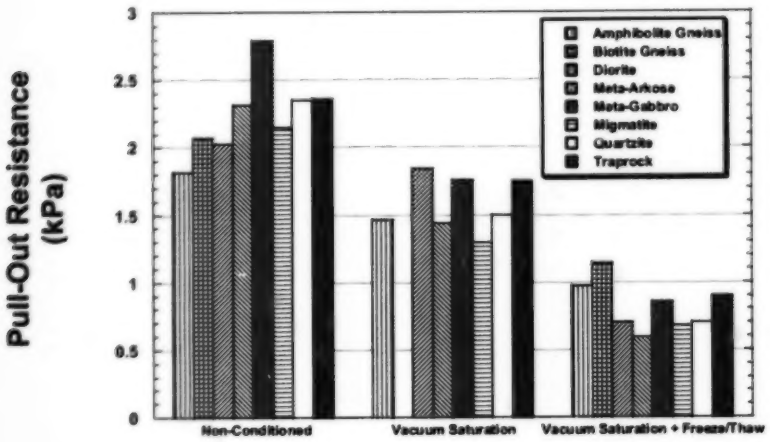


Figure 6 - Pull-Out Resistance Versus Conditioning Method (Sealant "A" – 20 by 20 Rout Cross Section)

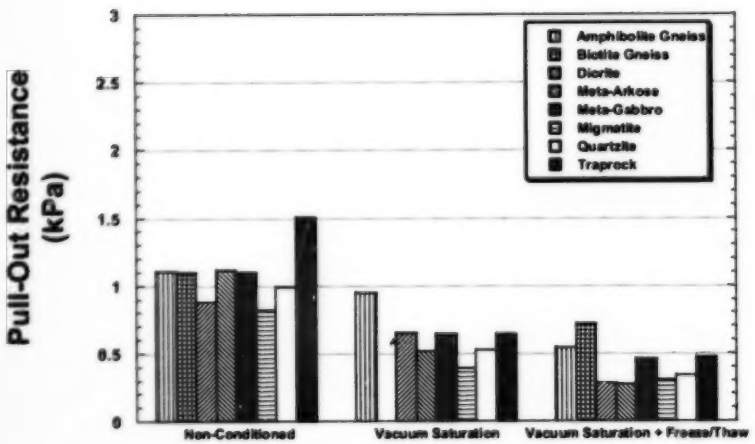


Figure 7 - Pull-Out Resistance Versus Conditioning Method (Sealant "B" – 40 by 10 Rout Cross Section)

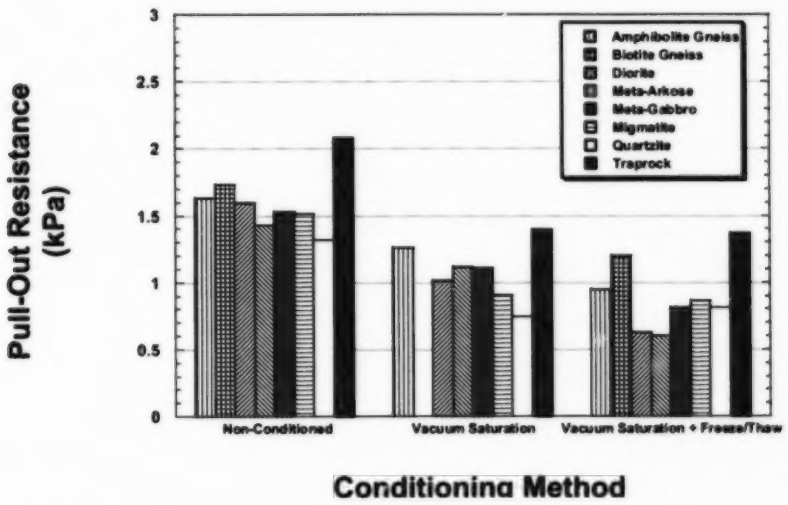


Figure 8 - Pull-Out Resistance Versus Conditioning Method (Sealant "B" – 20 by 20 Rout Cross Section)

Figure 9 summarizes the data for both sealants and the 40 X 10 rout configuration but only when the samples are vacuum saturated and followed by one freeze/thaw cycle. Figure 10 shows similar results for the 20 X 20 rout configuration.

Figure 11 compares the average results for the 40 X 10 and 20 X 20 rout cross sections for all 8 aggregate types, both sealants and all 3 conditioning methods.

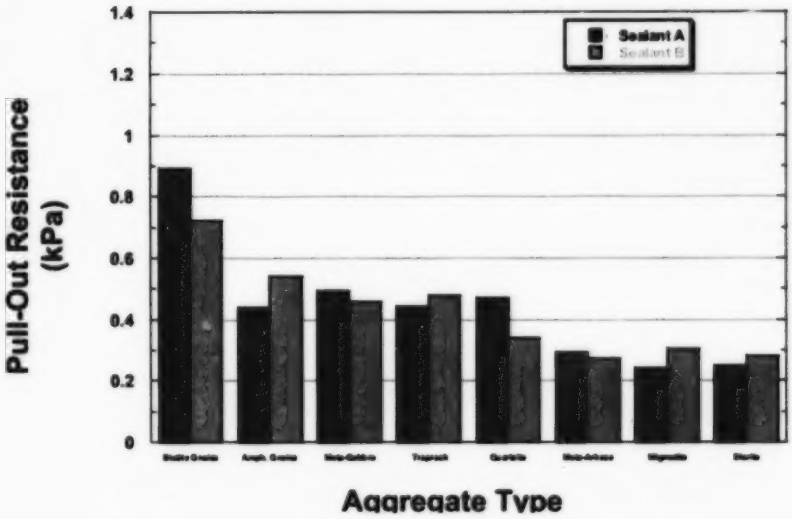


Figure 9 - Pull-Out Resistance By Aggregate Type - Vaccuum Saturation and One Freeze/Thaw Cycle - 40 by 10 Rout Cross Section

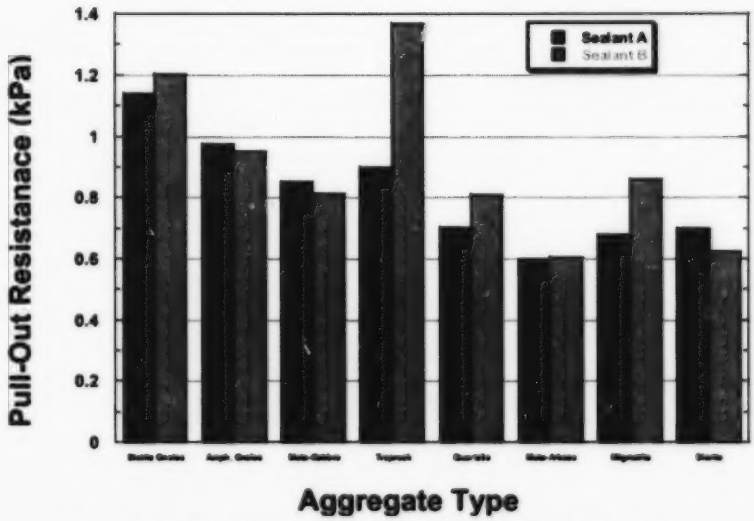


Figure 10 - Pull-Out Resistance By Aggregate Type - Vaccuum Saturation and One Freeze/Thaw Cycle - 20 by 20 Rout Cross Section

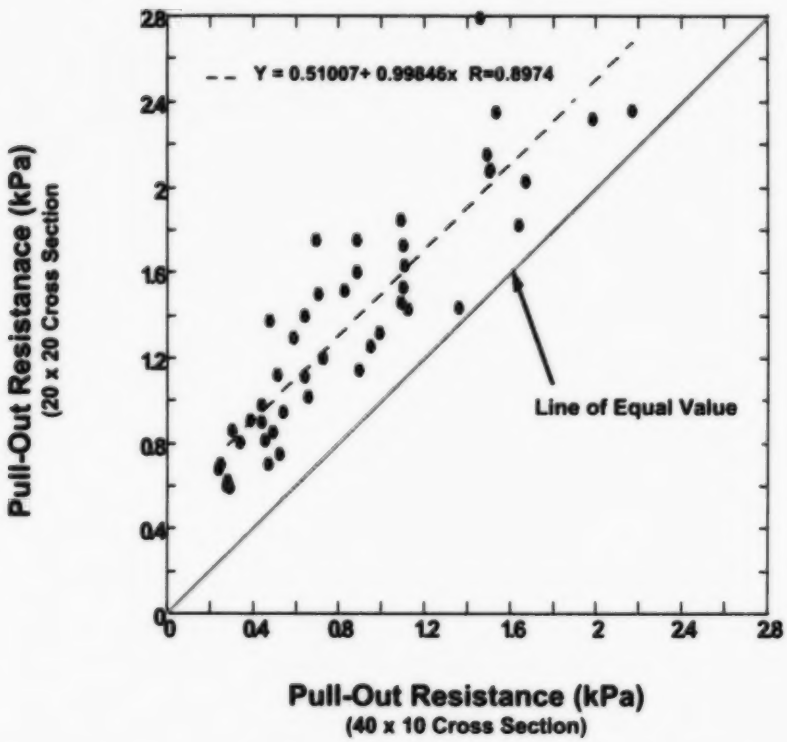


Figure 11 - Comparison of 40 x 10 and 20 x 20 Cross Sections
(Averages of All Aggregate Types and Conditioning Methods)

Summary of Findings

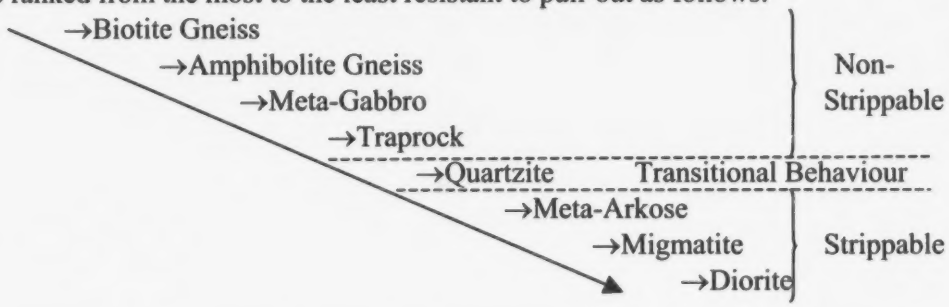
The results of the laboratory investigations can be summarized in the following statements:

1) The pull-out resistance for tests conducted using Sealant "A" was generally higher than similar tests conducted using Sealant "B".

2) The pull-out resistance of all of the aggregates was highest for the non-conditioned samples and lowest for the samples that were moisture-conditioned followed by one freeze/thaw cycle finishing with a hot bath.

3) Sealants tested in hot mix samples comprised of felsic (i.e. feldspar-rich) aggregates such as meta-arkose and diorite that were not conditioned or only subjected to vacuum saturation, often exhibited similar pull-out resistance to sealants tested in hot mix samples comprised of mafic (i.e. dark mineral-rich) traprock and meta-gabbro aggregates. However, when the same sealants were tested in hot mix samples derived from felsic aggregates but subjected to one additional freeze/thaw cycle followed by a hot bath, the differences between aggregates became much most pronounced and sealants in samples derived from felsic aggregates exhibited significantly less pull-resistance than similar tests of sealants in samples derived from the mafic aggregates.

4) Based on the combined averages of both sealants on samples that were vacuum saturated followed by one freeze-thaw cycle, the aggregate lithologies can generally be ranked from the most to the least resistant to pull-out as follows:



It should be noted, however, that there appeared to be relatively little difference between the three least pull-out resistant aggregates that were investigated. In any case, the ranking generally confirms what has been observed in the field.

5) The 20 mm wide by 20 mm deep rout configuration was found to average about 0.5 kPa (or 25 to 125%) higher pull-out resistance than the 40 mm wide by 10 mm deep configuration, regardless of the aggregate lithology, the type of sealant or the conditioning method that was used during the testing.

Conclusions

1) Pull-Out Resistance

Based on this testing and observations in the field, the performance of sealants in pavements comprised of aggregates with high mafic mineral content like the amphibolites, gabbros and traprocks perform better than sealants in pavements comprised of the more felsic aggregates like the meta-arkoses, migmatites and diorites.

The performance of sealants in pavements comprised of highly siliceous aggregates like quartzite can be expected to be quite variable. However, they will generally perform better than the performance of sealants in pavements comprised of the felsic aggregates.

Although workmanship is still considered to be the most important factor in the success or failure of hot-poured rubberized asphalt sealants, it appears that orthoclase or plagioclase feldspar minerals, which are quite brittle and have planar cleavage faces, are a major factor in such failures.

2) Rout Cross Section

This investigation has clearly shown that the tests using the 20 mm wide by 20 mm deep rout cross section resulted in consistently higher pull-out resistance than tests using the 40mm wide by 10 mm deep cross section. However, when these two rout configurations have been compared in the field, the opposite has often been found to be true. This is because contractors have had much more difficulty keeping meandering cracks inside the 20 mm wide rout width. Since debonding failures invariably begin where the edge of a crack meanders closest to the edge of the rout, this is why more failures have been found with the narrower rout. Therefore it appears that if the contractors are able to properly centre the rout over the crack, the 20 mm wide configuration is likely to outperform the wider configuration that is currently being used by MTO. It may be prudent to adopt a deeper rout cross section like the 20 mm wide by 20 mm deep rout for general use but only if the centreline tolerances for crack versus rout can be strictly enforced or to consider an alternative like the 30 mm wide by 15 mm deep rout cross section recommended by the National Research Council.

Future Work

A laboratory procedure is currently being written which will present the details of the Pull-Out resistance test that has been described in this investigation.

Once this test procedure has been completed, the intent will be to conduct a testing matrix involving all of the sealants currently on MTO's Designated Sources of Materials List (DSM) and mixes comprised of felsic or highly siliceous aggregates. This could also involve a comparison of the 20 mm wide X 20 mm deep rout cross section with another rout cross section such as the 30 mm wide by 15 mm wide cross section which is being recommended by the National Research Council. The eventual goal of this work will determine:

a) Which sealants that are currently on the DSM that will likely perform the best in pavements comprised of aggregates known to be prone to pull-outs and;
b) The fabricated rout cross section that results in the highest pull-out resistance, regardless of other factors (which could be adopted for general use by the MTO).

Acknowlegements

The Authors wish to express their thanks to Ho-lik Iu (MTO's Central Region) for his tireless effort in preparing the samples and assisting with the testing. Without his efforts, this work would not have been possible.

The Authors would also like to thank Jim Pretty, Howard Sahsuvaroglu and Wayne Kelly of the Bituminous Section for their assistance during the sample preparation and compatibility tests; Concrete Section's Stetin Barrow and Hannah Schell for providing the sealant application equipment and their expertise and the Soils and Aggregates Section's Chris Rogers, Ray Ramasray and Tyrone Gilbank for their assistance during the preparation of the aggregates.

Finally, the Authors would like to acknowledge the contribution by Allison Geist and Dave McNeely (of Eastern Region) in procuring samples and assisting with the initial development of the test procedure.

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Appendix 1

Some Ontario-Specific Mix Designations:

- DFC: A premium, dense-graded, surface course mix with high frictional resistance consisting of 100% high quality, crushed aggregates having the same gradation as HL 1. It is used only on freeways in Southern Ontario with volumes greater than 5000 AADT per lane.

- HL1: A dense-graded surface course mix consisting of premium quality, crushed, coarse aggregates with a maximum aggregate size of 16 mm. It is normally used on roads with volumes between 2500 and 5000 AADT per lane.

- HL3: A dense-graded surface course mix with similar gradation to HL1 but with lower quality requirements for the aggregates.

- HL3 Mod: A dense-graded surface course mix, with coarse aggregate superior to HL3. It is essentially equivalent to HL1, but the coarse aggregate is not currently on an Ontario-approved HL1 list.

- HL4: A surface or binder course mix with a maximum aggregate size of 19.0 mm. It is primarily used on two-lane highways in Northern Ontario or as a binder course in Southern Ontario where HL8 is not available.